Activity 2

Solid, Liquid, or Gas?

What Do You Think?

A number of toys use gases.

• What makes a gas different from a liquid or a solid?
• Why are some substances gases at room temperature, while others are not?

Record your ideas about these questions in your Active Chemistry log. Be prepared to discuss your responses with your small group and the class.

Investigate

Part A: Size and Shape of Molecules

1. Look at the following computer-drawn diagrams of molecules.

   *Shape and relative size of diatomic halogen molecules*

   - fluorine $F_2$
   - chlorine $Cl_2$
   - bromine $Br_2$
   - iodine $I_2$
2. In your Active Chemistry log record your answers to the following questions.

a) What do you notice about the shape of the diatomic halogen molecules? How do their sizes compare?

b) What do you notice about the shape of the CX₄ molecules? How do their sizes compare?

c) The hydrocarbon and alcohol molecules are similar. CH₄ is methane and CH₃OH is methanol. C₂H₆ is ethane and C₂H₅OH is ethanol. The other pairs are propane and 1-propanol, and butane and 1-butanol. What is the difference between each of the pairs of molecules? Look carefully at their shapes. Describe any differences that you notice between the pairs of molecules.

Part B: Boiling and Melting Point of Molecules

Room temperature is about 22°C. If a substance has a boiling point below room temperature, it must be a gas at room temperature. If its boiling point is above 22°C, then it is a liquid (or possibly a solid) at room temperature. If its melting point is above 22°C, then it is a solid at room temperature.
1. Look at the table showing the melting and boiling points of halogens.

<table>
<thead>
<tr>
<th>Substances</th>
<th>Melting point (°C)</th>
<th>Boiling point (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>( F_2 ) (fluorine)</td>
<td>–220</td>
<td>–188</td>
</tr>
<tr>
<td>( Cl_2 ) (chlorine)</td>
<td>–101</td>
<td>–34</td>
</tr>
<tr>
<td>( Br_2 ) (bromine)</td>
<td>–7</td>
<td>59</td>
</tr>
<tr>
<td>( I_2 ) (iodine)</td>
<td>114</td>
<td>185</td>
</tr>
</tbody>
</table>

Answer the following in your Active Chemistry log.

a) Fluorine will be a solid at any temperature less than its melting point of –220°C. At –220°C, fluorine melts and becomes a liquid. The liquid then heats up until it reaches the boiling point of –188°C. At that temperature the fluorine becomes a gas and remains a gas for all higher temperatures. Which of the halogens are gases at room temperature of 22°C? Which are liquids? Which are solids?

b) Since all of the halogens have the same shape, what is the difference between those that are gases and those that are liquids or solids at room temperature?

2. Look at the table showing the melting and boiling points of \( CX_4 \) compounds.

<table>
<thead>
<tr>
<th>Melting and Boiling Points of ( CX_4 ) Compounds</th>
</tr>
</thead>
<tbody>
<tr>
<td>Substance</td>
</tr>
<tr>
<td>-----------------------------</td>
</tr>
<tr>
<td>( CH_4 ) (methane)</td>
</tr>
<tr>
<td>( CF_4 ) (carbon tetrafluoride)</td>
</tr>
<tr>
<td>( CCl_4 ) (carbon tetrachloride)</td>
</tr>
<tr>
<td>( CBr_4 ) (carbon tetrabromide)</td>
</tr>
</tbody>
</table>

Answer the following in your Active Chemistry log.

a) Of the \( CX_4 \) compounds, which are gases, liquids, and solids at room temperature?

b) Since all of the \( CX_4 \) compounds have the same shape, what is the difference between those that are gases at room temperature and the ones that are liquids or solids?

3. Hydrocarbons are simply molecules made up of carbon and hydrogen. Alcohols are molecules containing an –OH group. Note the difference between methanol (\( CH_3 OH \)) and sodium hydroxide (\( NaOH \)). Both have an OH in the formula, but the alcohol is a covalently bonded molecule and \( NaOH \) is an ionic compound, not a molecule.
Look at the graph showing the boiling points of hydrocarbons and alcohols.

Answer the following in your *Active Chemistry* log.

a) Which substances are gases at room temperature? Which are liquids?

b) Examine the boiling points of the series of hydrocarbons. What is the general trend as the number of carbons increases? That is, what happens to the boiling point as the number of carbons (and thus the size of the molecule) increases?

c) Now look at the boiling point differences between the pairs of methane/methanol, ethane/ethanol, propane/1-propanol, and butane/1-butanol. What factor could contribute to the large difference in boiling points for each pair?

4. Based on the information that you have, what two factors can be used to form a general rule to determine if a substance is a solid, a liquid, or a gas at room temperature? Explain the relationship between these factors and the boiling points of the substances.

**ChemTalk**

**INTERMOLECULAR FORCES**

**Intermolecular Forces in Liquids, Solids, and Gases**

Gases are different from liquids and solids. In solids, the molecules or atoms that form the substance are in an orderly crystalline structure. They are locked in place and are not able to move around much because the atoms have a fairly strong attraction for one another. These attractions are electrical in nature, meaning they are related to the number and position of the molecules’ electrons. Motion of the atoms of solids consists of vibrating in place. In liquids, the molecules or atoms are still in contact with each other, but they are not locked in place. The particles vibrate and are able to move...
around each other. The molecules of liquids have less attraction for one another than the molecules of solids. The molecules or atoms of a gas have very little contact with each other because they have very little attraction for one another. All molecules have some attraction but some are very weak. If you take nitrogen gas and slow the molecules down by cooling it, the attractions will become strong enough that the gas will liquefy. If you cool it enough, it will freeze and become a solid. These attractions or forces between molecules are called **intermolecular forces**. The fact that there is a lot of space between the particles of a gas accounts for the reason that it is easy to compress gases.

### Non-polar Molecules

Halogens, oxygen, nitrogen, carbon dioxide, and the CX₄ molecules have shapes that are symmetrical. The electrons of these molecules are distributed evenly in such a way that there are no permanent partial electric charges anywhere on the molecules. These molecules are said to be **non-polar**. The symmetrical shapes of non-polar molecules cause them to have very little attraction for each other. Small, non-polar molecules tend to have low boiling points.

As the size of non-polar molecules increases, the attractive forces between molecules also begin to increase. You saw this for the series of hydrocarbon molecules. Larger molecules have more electrons and when there are a greater number of electrons they may, at one instant, be distributed unevenly. One part of the molecule may have, only for the briefest of moments, an increased number of electrons. This distortion of electrons gives rise to a temporary partial negative charge (represented by the Greek letter delta, δ⁻). Since one part of the molecule has an overabundance of electrons another part of the molecule must have a deficiency of electrons, creating a partial positive charge (δ⁺) on that part of the molecule.

The molecule becomes a temporary dipole (meaning two poles or two charges). This in turn triggers (induces) a similar dipole in neighboring molecules and this process spreads from molecule to molecule. These attractive forces, called **London dispersion forces**, are much weaker than ionic or covalent bonds which hold atoms together. The polarity causes a greater attraction between molecules. The molecules are difficult to separate, which is what takes place when a substance boils. The larger molecules tend to have higher boiling points and can be liquids or solids at room temperature.
Polar Molecules

Other molecules have a permanent polarity due to their shape and/or the types of atoms in the molecule. Some elements have a greater tendency to pull the electrons of a covalent bond toward themselves. This property is called electronegativity. Oxygen is more electronegative than hydrogen so the electrons in the O–H bond are pulled closer to the oxygen atom. This creates a partial negative charge on the oxygen and a partial positive charge on the hydrogen atoms. These partial charges are permanent, not fleeting, like the dispersion forces.

Water molecules have two hydrogen atoms attached to the oxygen atom at an angle of about 107.5°. The electronegativity differences and the shape of the molecule cause the molecule to be polar.

Even though water molecules are very small, their polarity allows them to attract other water molecules. (You can represent the water molecule as shown in the diagram.)

You can then imagine how the molecules will interact with one another.

While this is a simplified picture of what occurs (the actual three-dimensional orientation of the molecules is more complicated), it gives you an idea of the forces between molecules. These intermolecular forces between water molecules are called hydrogen bonds. When there is a strong attraction between molecules, the substances are probably liquids or solids at room temperature. The alcohols discussed in this activity have an –OH group that makes these molecules polar in nature. Just like in water, this polarity increases the amount of energy needed to separate the molecules, increasing the boiling point of alcohols.

Checking Up
1. What is meant by a molecule’s polarity?
2. What are London dispersion forces?
3. Which would have a greater boiling point: C₆H₁₂ or C₇H₁₆?
What Do You Think Now?
At the beginning of this activity you were asked:
• What makes a gas different from a liquid or a solid?
• Why are some substances gases at room temperature, while others are not?
Revisit your initial responses to these questions. Now add to or modify your thoughts in light of what you learned in this activity.

Chem Essential Questions

What does it mean?
Chemistry explains a macroscopic phenomenon (what you observe) with a description of what happens at the nanoscopic level (atoms and molecules) using symbolic structures as a way to communicate. Complete the chart below in your Active Chemistry log.

<table>
<thead>
<tr>
<th>MACRO</th>
<th>NANO</th>
<th>SYMBOLIC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Explain the visible macroscopic features of a solid, a liquid, and a gas.</td>
<td>Compare and contrast the nanoscopic nature of a solid, a liquid, and a gas.</td>
<td>Make sketches of water molecules in the solid state (ice), the liquid state, and the gas state.</td>
</tr>
</tbody>
</table>

How do you know?
What conclusions can you draw regarding the shape of a molecule and its physical state? Use data from this activity to support your ideas.

Why do you believe?
It is important to have an understanding about the nature of matter in its different states. In this activity there was a discussion of how cooling a gas could cause it to liquefy by slowing the molecules enough to allow them to attract each other. In boiling, the increase in energy allows the molecules to move apart despite their intermolecular attractive forces. Provide a similar discussion of what happens at the molecular level when a chocolate bar melts or how ice forms on a windshield overnight even though it didn’t rain. Be sure to include intermolecular forces in your discussion.

Why should you care?
Your toy design may include the use of a gas such as you find in toy rockets, or some high-tech water guns. Explain the nature of gas particles as you would in your toy project, if a gas were involved in your toy.
Reflecting on the Activity and the Challenge

You now understand that the size and shape of molecules determine whether or not the substance is a gas at room temperature. The molecules of most gases at room temperature show very little attraction for one another, and there is a lot of space between the molecules. Because of this, gases are easily compressed, which is something that is not easily done with most liquids and solids. Your toy may take advantage of the compressibility of gases.

1. Explain why most gases have very little attraction between their molecules.
2. Ignoring the electronegativity values of the atoms, label each molecule as polar or non-polar based on shape alone.
   a) 
   b) 
   c) 
3. a) Rank the molecules listed in Question 2 from lowest to highest boiling points.
   b) Only one is a liquid at room temperature. Which one is it?
4. Water is a liquid at room temperature while methane is a gas. Which of the following statements correctly describes the intermolecular forces between these molecules?
   a) Water and methane basically have no intermolecular forces.
   b) The intermolecular forces in water are stronger than those of methane.
   c) The intermolecular forces in methane are stronger than those of water.
   d) More information is needed in order to compare the intermolecular forces.
5. Under which conditions do you think you could dissolve the most gas in a liquid: (Hint: Think of a carbonated soda-carbon dioxide dissolved in water.)
   a) low pressure and high temperature
   b) low pressure and low temperature
   c) high pressure and low temperature
   d) high pressure and high temperature
6. Draw sketches and compare:
   a) methane and methanol
   b) methane and carbon tetrachloride
   c) fluorine and carbon tetrachloride

7. Preparing for the Chapter Challenge

Prepare a list of all of the toys you know that use a gas in some manner. List the gases used and the purpose of each gas.